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MAXIMIZATION OF PHOTOVOLTAIC ENERGY GENERATION BY TIME AND LOCATION BASED SUN TRACKING SYSTEM

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ABSTRACT

This paper presents time and location based sun tracking system which maximizes the exposure of the sun to the photovoltaic panel used for energy generation. This unprecedented tracking system is location and time agnostic which facilitates an easy installation at any place without any manual calibration. The system works on Program Logic Controller, which is programmed in such a way that it calculates the position (inclination) of the panel based on the current time and location. An experimental prototype is built and deployed for which calculations and inclination control approach is presented, as a proof. It is found that the average power generation is increased using the proposed novel tracking system.

KEYWORDS: Solar Tracking, Photovoltaic panel & Program Logic Controller

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Original Article

INTRODUCTION

Our ecosystem and the earth's climate and weather is sources of sun's energy, that is sunlight. Harnessing this energy for electrical power is the greatest potential of all sources of renewable energy, a low carbon energy source and an attractive way of soothing the climate change. Solar technologies are already in use in many countries to enhance the standard of living and is a natural choice where solar influx is high and grid services are unavailable Solar electricity can be generated using photovoltaic (PV) panels. These panels are suitable for use on roofs and are manufactured in sufficient quantity. Also the electricity generated from these panels in favourable locations has reached grid parity. It is possible to sell surplus electricity back to the grid if a feed-in tariff is in place. However, the best utilization of the solar energy is when the sun and the young flowers are in the same line, rotating from east to west. And this process is referred to as heliotropism. It’s a clever bit of natural engineering. Similarly a solar tracking system based on the current location on the earth during the day, this scheme is designed for power generation from the sunlight. In this a GPS system is used to calculate the position of the solar panel. The functions of the photovoltaic panel, at regular time-base are pre-programmed. In this scheme the maximum day light is utilised by the solar panel to generate the power to its fullest capacity.

SOLAR TRACKING SYSTEM

There are significant efforts on the optimization of sun tracking systems as it is documented by several registered international patents. The above described principle is based either on the quantification of the energy received from the sun or on the maximization of the solar incident radiation through the use of light concentrations lens [1], [2]. The result of this study in innovative in connection with the above referred approaches as this system

is autonomous regarding the information needed to process the optimal orientation and the real-time base for photovoltaic energy generation. There are several methods to drive solar trackers, namely Active tracking, Passive tracking, Chronological tracking and Manual tracking. Motors and gear trains are made use of by theactive trackers to direct the tracker as commanded by the controller responding to the solar direction. Throughout the day the direction of the sun is monitored. In darkness the tracker either sleeps or stops depending on the design. This is done using sensors that are sensitive to light such as Lower Density Radiations (LDR). Panel adjustment is done by the actuators which is driven by microcontrollerinto which their voltage output is put. In case of an imbalance the passive trackers use a low boiling point compressed gas fluid driven to one side or the other to cause the tracker to move. Due to its non-precision orientation it is found not suitable for some types of concentrate photovoltaic collectors but works just fine for common PV panel types. These have viscous dampers that prevent excessive motion in response to gusts of wind. A chronological tracker counter acts the rotation of the earth by turning at the same speed to that of the sun that rotates around its axis and is parallel to the earth. A simple rotation mechanism is devised which enables the system to rotate throughout the day in a predefined manner without considering whether the sun is there or not. The system turns at a constant speed of one revolution per day or 15 degrees per hour. Chronological trackers are very simple and accurate. As the name suggests manual tracking is operated manually whenever the need is observed. Here the operators replace the drives who adjust the trackers. This has the benefits of wholeness if staff is available for maintenance. There are two basic types of solar tracker systems, namely Single axis and Dual axis trackers. Single axis trackers have one degree of freedom thatacts as the axis of rotation. The axis of rotation of single axis trackers is aligned along the north meridian. With advanced tracking algorithms, it ispossible to align them in any cardinal direction. Common implementations of single axis trackers include i) Horizontal single axis trackers (HSAT), ii) Horizontal single axis tracker with tilted modules (HTSAT), iii). Vertical single axis trackers (VSAT), iv) Tilted single axis trackers (TSAT) and v) Polar aligned single axis trackers (PSAT).

Dual axis trackers have two degrees of freedom that act as axes of rotation and these are typically normal to each other. The primary axis is the one that is fixed with respect to the ground and the secondary axis is the one referenced to the primary axis. Dual trackers have various common implementations. Their classification is based on the exposure of their primary axes with respect to the ground. The factors which affects the solar tracker efficiencies are Panel Orientation, Roof and Panel Pitch, Temperature and Shade which we briefly explain below.

Panel Orientation: Solar panel orientation depend upon Azimuth and Zenith angle Azimuth – This is the compass angle of the sun as it moves through the sky from East to West over the course of the day. Azimuth is calculated as an angle from true south, that is towards the southern end of the axis about which the earth rotates. The wrong azimuth angle could reduce the energy output of a solar PV array down to 35%. Zenith – This is the angle of the sun from the ground level or the horizon. The zenith angle of the sun varies throughout the day in the form of an arc with the sun reaching its maximum elevation (also called solar altitude) around midday.

Roof and Panel Pitch: The “pitch” or tilt of roof can affect the number of hours of sunlight you receive on an average day throughout the year. Large commercial systems have solar trackers that automatically follow the sun’s tilt through the day.

Temperature: Panels need to be installed a few inches above the roof with enough air flow to cool them down. Some photovoltaic panels are designed to be more efficient in hotter climates.

Shade: Basically, shade is the enemy of solar power. Incase of a poor solar design, even a little shade on one panel can shut down energy production from all the other panels too (like a bad bulb in a string of series-lights).

REVIEW OF SOLAR TRACKING SYSTEM

In 1975, McFee presented the first automatic solar tracking systems in which an algorithm was developed to compute the total received power and flux density distribution in a central receiver solar power system. Each mirror was subdivided into 484 elements and the sum of all elements' contributions determines the sun, with a tracking error tolerance of 0.5° – 1°. For the sun to point toward the flower at all times, a simple microprocessor was used to adjust the positions of the solar collectors in a photovoltaic concentrator. This method was used by Semma and Imamru several years later. The algorithms of determining sun position was further improved by the mathematical theories of tracking error distributions [3]. In 1983, a solar tracking system consisting of a two-axis equatorial mount and a microprocessor was developed by Al-Naima and Yaghobian., This technique was based on the astronomical coordinates of the sun. It was shown that the above-mentioned system was capable of better tracking than that obtained by a conventional sensor-controlled system [4]. Several years later, Lorenz proposed a window glazing method wherein a set of design guidelines for window glazing that rejected solar radiation during the summer but accepted it during the winter. A purely passive control algorithm is the basis of seasonal changes in the incident angle of the solar rays [5]. In 1990, a microprocessor-based controller for solar tracking was proposed by Ashok Kumar Saxena and V. Dutta, wherein the controller had the capability of acquiring photovoltaic and meteorological data from a photovoltaic system, controlling the battery/load. For those system used for system control and monitoring remote areas, it was found to be useful in autonomous PV systems. In both open loop and closed loop modes, solar tracking was achieved. This system proved useful as the controller was totally automatic and required an operator's interference only on a need basis. [Ashok Kumar Saxena and V. Dutta, 1990] [6]-[7]. A microprocessor-based automatic position control scheme was proposed by A. Konar and A. K. Mandal, in 1991. Maximum solar irradiance was collected by controlling the azimuth angle of an optimally tilted photovoltaic flat-type solar panel or a cylindrical parabolic reflector to get the illuminating surface appropriately positioned, thereby saving energy. Designed as a pseudo tracker, this has been designed to keep the motor idle to save energy. The location where the solar panel was located did not affect proper direction especially when the system tries to find the sun, proving very efficient because of its energy-saving mode. [A. Konar and A. K Mandal, 1991] [8].

Irradiation is the exposure of an object to radiation, excluding the exposure to non-ionizing radiation such as infrared, visible light, microwaves from cellular phones or electromagnetic waves emitted by radio and TV receivers and power supplies [9]. In 1992, Agarwal presented a two-axis tracking system consisting of worm gear drives and four bar-type kinematic linkages to facilitate the accurate focusing of the reflectors in a solar concentrator system. In the same year, Enslin applied the principles of maximum power point tracking (MPPT) to realize a power electronic converter for transforming the output voltage of a solar panel to the required DC battery bus voltage [10].

In 1997, Zeroual designed an automatic sun-tracker system for optimum solar energy collection, using electro-optical sensors for sun finding and a microprocessor controller. For optimum efficiency, solar energy collectors were used to follow the sun's position. The solar tracker system had a modular structure that facilitates its application to different systems without any modifications. The system had been applied to water heating solar system for domestic uses houses. The system security is controlled for parameters such as temperature, pressure and wind velocity. The solar tracker system had been tested for a long period in various sunlight, showing high accuracy. The system is also very efficient for our solar

tracker, with use in heating and cooling systems in the houses. [A. Zeroual et al., 1997] [11]. To enhance the thermal performance of a compound parabolic concentrator, Khalifa and Al-Mutawalli (1998) developed a two-axis sun tracking system,, tracking the sun's position every three to four minutes in the horizontal plane and every four to five minutes in the vertical plane. The tracking system comprised two identical sub-systems, one for each axis, with each sub-system consisting of two adjacent photo-transistors separated by a partition of a certain height. In the tracking operation, the difference in the voltage signals of the two photo-transistors was amplified and used as a command signal to drive the collector around the corresponding axis until the voltage difference reduced to zero, indicating that the sun's rays were once again normal to the collector surface [12]. In 2004, Roth et al. designed and constructed a sun tracking system that used a pyrheliometer to measure the direct solar radiation. The system was controlled by a closed-loop servo system consisting of a four-quadrant photo detector to sense the sun's position and two small DC motors to drive the instrument platform in such a way that the sun's image remained at the center of the four-quadrant detector at all times [13]-[14]. In 2004, Abdallah and Nijmeh developed an electro-mechanical, two-axis tracking system in which the motion of the sun tracking surface was controlled by an open-loop control algorithm implemented using a PLC unit. A programmable logic controller, PLC, or programmable controller is a digital computer used for automation of typically industrial electromechanical processes, such as control of machinery on factory assembly lines, amusement rides, or light fixtures. The proposed system consisted of two separate tracking motors, one to rotate the sun tracking surface about the horizontal north-south axis, i. e. to adjust the slope of the surface and the other to rotate the sun tracking surface about the vertical axis, i. e. to adjust the azimuth angle of the surface [15]. Three sun tracking systems, namely, (1) one-axis sun tracking with the tilted aperture equal to the latitude angle, (2) Equatorial two-axis sun tracking, and (3) azimuth/elevation sun tracking were proposed by Alata et al. in 2005.

The first-order Sugeno fuzzy inference system was used for modeling and controlling design tasks. The first two parts of the fuzzy inference process are exactly the same, fuzzifying the inputs and applying the fuzzy operator[16].

Based on a sliding mode controller (SMC), Kim (2007) presented a robust Maximum Power Point Tracking (MPPT) system for a three-phase grid-connected photovoltaic system, comprising a MPPT controller and a current controller. The MPPT controller generated a current reference directly from the solar array power information, while the current controller used an integral sliding mode scheme to ensure a tight control of the current [17]. A sun sensor algorithm-based analogue optical nonlinear compensation measuring principle was adopted by Chen et al. (2007). Above a quadrant detector is placed a thin mask with a square aperture consisting of four slits of equal width, comprising a traditional sun sensor. Depending on its angle relative to the main sensor axis, the incident sunlight illuminates different positions of the detector and forms a projective image on the detector's plane [18]-[19]. According to Dante Johnson-Hoyte et al., a highly portable, efficient solar tracker can be great use to applications of the military, industrial, or residential variety. For an efficient solar generation system, it is necessary to design, build, and test solar tracker. At most, the solar tracker was 3 degrees perpendicular to the light source [20].

Hashem Bukhamsin et al (2013) demonstrated the difference in power generation of a solar tracker to a static solar panel. For this system, the base structure design has been modified. For easy mobility, it depends on a free standing box structure [21]. Again in 2013, S. Lakeou et al demonstrated that during the course of the year, the array will be tilted around the X-axis progressively from June 21 to December 21 in one direction and from December 22 to June 20 in the opposite direction. For a simple tracking system, the daily solar tracking is achieved by rotating the array about the solar

tracking axis Y, by equal incremental angular steps $\Delta\phi$ = 150 [22]. Dhanabal R (2013) the LDR with the maximum intensity of the sun's radiation sends stronger signal to the controller which in turn sends signal to the motor to rotate the panel in the direction in which the sun's intensity is maximum [23]. A solar tracker is a device for orienting a solar photo voltaic panel, day lighting reflector or concentrating solar reflector or lens toward the sun, according to ShrishtiRana (2013). Solar power generation is at its best when the tracker is pointed directly at the sun, increasing the effectiveness of such equipment over any fixed position. For maximum energy generation, it is necessary that the solar panels are perpendicular to the sun's rays.

PROPOSED NOVEL SOLAR TRACKING SYSTEM AND ITS PERFORMANCE

The GPS-based tracking system with step motor is shown in figure 1.

Figure1: Novel Solar Tracking System

Novel solar tracking systemcomponents are as follows:

1. driving unit, 2. control unit, 3. mechanical structure, and 4. solar photovoltaic panel. The driving unit consists of D. C motor and stepper motor. The control unit consists of printed circuit board, 89C51/52 Microcontroller IC, 2N5296 NPN Epitaxial Silicon Transistor, LM 555 Timer IC, Voltage Regulators (7805 & 7815), Reset button, Led bulbs, Limit Switches. A solar Photovoltaic panel of 10 W capacity is used in this prototype.

The below calculations are taken on 10 watts 12volt solar panel.

Table 1: Amount of Power Produced by the 10W Solar Panel at Every Hour Per a Day

Tracker				
S. No	**Time**	**Volts**	**Amps**	**Watts**
1	8:00	6	0.8	4.8
2	9:00	6	0.9	5.4
3	10:00	6.1	1.0	6.1
4	11:00	6.3	1.1	6.93
5	12:00	7	1.2	8.4
6	13:00	8	1.2	9.76
7	14:00	8.2	1.2	9.84
8	15:00	8.1	1.2	9.72
9	16:00	7.6	1.1	8.36
AVERAGE		**7.0**	**1.1**	**7.7**

$$Percentage = \frac{SolartrackinginWatts - SolarstaticsinWtts}{SolarStaticsinWatts} \times 100$$

$$= \frac{7.7-3.9}{3.9} \times 100 = 88\%$$

To rotate the solar panel from east to west and reverse direction, a DC stepper motor of 10 R. P. M, 12V is used.

- The motor takes 24mA at 12V dc.
- So, the required Power = 24mA*12V = 288mW/sec.
- For 6 sec, the required power =288*6=1728mW=1.8W.

Each day, the panel (or motor) moves east to west and back to east.

For 10 rotations, the motor takes 1 min/60 sec.

Therefore, for 1 rotation (360˚) the motor takes (60/10) = 6 sec.

To rotate from east to west (180 ˚) the motor takes 3 sec.

So, for 10 degree displacement it takes (3000ms*10˚)/180˚ = 167msec.

In generally, the moves from east to west i. e. 180˚ in 12 hours (6 am to 6 pm) or 720mins.

For 10˚ displacement, the sun takes 720/180= 40 mins.

So, in 2 hrs the sun travels 30degree. To cover this 30degree displacement the panel takes (167*3) = 501msec

The main task performed by the system is to control the two step motors based on the solar position calculations as explain below.

First, the fractional year (γ) is calculated, in radians.

γ= (2 *pi/365)*(day_of_year−1+ (*hour*−12)/24)

(For leap years, one may use 366 instead of 365 in the denominator.)

From γ, we can estimate the equation of time (in minutes) and the solar declination angle (in radians).

eqtime = 229.18*(0.000075 + 0.001868cos(γ) – 0.032077sin(γ) – 0.014615cos(2γ) – 0.040849sin(2γ))

decl = 0.006918 – 0.399912cos(γ) + 0.070257sin(γ) – 0.006758cos(2γ) + 0.000907sin(2γ) – 0.002697cos(3γ) + 0.00148sin (3γ)

Next, the true solar time is calculated in the following two equations. First the time offset is found, in minutes, and then the true solar time, in minutes.

time_offset = *eqtime* + 4**longitude* – 60**timezone*

where eqtime is expressed in minutes, longitude is in degrees (positive to the east of the prime meridian), timezone is in hours.

tst = *hr**60 + *mn* + *sc*/60 + *time_offset*

where hr is hour (0 − 23), mn is minute (0 − 59), sc is second (0 − 59).

The solar hour angle, in degrees, is:$ha = (tst / 4) - 180$

The solar zenith angle (φ) can then be found from the hour angle (*ha*), latitude (*lat*) and solar declination (*decl*) using the following equation:$\cos(\varphi) = \sin(lat)\sin(decl) + \mathrm{cost}(lat)\cos(decl)\cos(ha)$

And the solar azimuth (θ, degrees clockwise from north) is found from:

$\cos(180-\theta) = -(\sin(lat)\cos(\varphi) - \sin(decl)) / (\cos(lat)\sin(\varphi))$

For the special case of sunrise or sunset, the zenith is set at 90.833° (the approximate correction for atmospheric refraction at sunrise and sunset, and the size of the solar disk), and the hour angle becomes:

$ha = \pm arccos\{\cos(90.833)/\cos(lat)\cos(decl) - \tan(lat)\tan(decl)\}$

where the positive number corresponds to sunrise and negative to sunset.

Then the time of sunrise (or sunset) in minutes is:$sunrise = 720 - 4*(longitude + ha) - eqtime$

where longitude and hour angle are in degrees and the equation of time is in minutes.

Solar noon for a given location is found from the longitude (in degrees, positive to the east of the Prime Meridian) and the equation of time (in minutes):$snoon = 720 - 4*longitude - eqtime$

CONCLUSIONS

The levels of power generation has shown good improvement when tracking was introduced in the area of solar PV cells. Further enhancement can be achievedby using dynamically controlled system. This article is about an automated dynamic system that overcomes the shortcomings of the existing systems. It is known for its easy installation at any place in the world. In addition, the step motor re-aligns the panel automatically for the rest of the day and then switches off. In instances of system failure, it automatically re-calibrates itself to the position of the sun, providing a practical approach in commissioning the solar tracker at any given location while providing maximum exposure of the sun to the solar panel.

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